CLAIMS

We claim:

1.   A method for constructing a multipurpose error-control code for multilevel memory cells operating with a variable number of storage levels, in particular for memory cells having storage levels that can assume values of the set $\{b^{a_1}, b^{a_1 a_2}, \ldots, b^{a_1 a_2 \cdots a_s}\}$, said error-control code encoding information words, formed by k q-ary symbols belonging to an alphabet containing q different symbols, with $q \in \{b^{a_1}, b^{a_1 a_2}, \ldots, b^{a_1 a_2 \cdots a_s}\}$, in corresponding code words formed by n q-ary symbols, with $q = b^{a_1 a_2 \cdots a_s}$, and having an error-correction capacity t, each code word being generated through an operation of multiplication between the corresponding information word and a generating matrix; said construction method comprising the steps of:

acquiring values of k, t, b^{a_1}, $b^{a_1 a_2}$, ..., $b^{a_1 a_2 \cdots a_s}$, which constitute design specifications of said error-control code;

calculating, as a function of $q = b^{a_1}$, k and t, the minimum value of n such that a Hamming limit is satisfied;

calculating the maximum values $\hat{n}$ and $\hat{k}$ of n and k that satisfy said Hamming limit for $q = b^{a_1}$, t and $(\hat{n} - \hat{k}) = (n-k)$;

determining, as a function of t, the generating matrix of the error-control code ($\hat{n}$, $\hat{k}$) on a finite-element field $GF(b^{a_1})$;

constructing binary polynomial representations of finite-element fields $GF(b^{a_1})$, $GF(b^{a_1 a_2})$, ..., $GF(b^{a_1 a_2 \cdots a_s})$;

identifying, using said exponential representations, elements of the finite-element field $GF(b^{a_1 a_2 \cdots a_s})$ isomorphic to elements of the finite-element fields $GF(b^{a_1})$, $GF(b^{a_1 a_2})$, ..., $GF(b^{a_1 a_2 \cdots a_{s-1}}))$;

establishing biunique correspondences between the elements of the finite-element fields $GF(b^{a_1})$, $GF(b^{a_1 a_2})$, ..., $GF(b^{a_1 a_2 \cdots a_{s-1}})$ and the elements of the finite-element field $GF(b^{a_1 a_2 \cdots a_s})$ that are isomorphic to them; and

substituting each of a plurality of elements of said generating matrix with a corresponding isomorphic element of the finite-element field $GF(b^{a_1 a_2 \cdots a_h})$, thus obtaining a multipurpose generating matrix defining, together with said biunique correspondences, said multipurpose error-control code that can be used with memory cells the storage levels of which can assume the values of the set $\{b^{a_1}, b^{a_1 a_2}, ..., b^{a_1 a_2 \cdots a_h}\}$.

2.   The construction method according to claim 1, in which said error-control code is a linear block code.

3.   The construction method according to claim 1, in which the identification of the elements of the finite-element field $GF(b^{a_1 a_2 \cdots a_h})$ isomorphic to the elements of the finite-element fields $GF(b^{a_1})$, $GF(b^{a_1 a_2})$, ..., $GF(b^{a_1 a_2 \cdots a_{h-1}})$ is performed on the basis of the multiplicity of said elements in the finite-element field $GF(b^{a_1 a_2 \cdots a_h})$.

4.   The construction method according to claim 3, in which said step of identifying the elements of the finite-element field $GF(b^{a_1 a_2 \cdots a_h})$ isomorphic to the elements of the finite-element fields $GF(b^{a_1})$, $GF(b^{a_1 a_2})$, ..., $GF(b^{a_1 a_2 \cdots a_{h-1}})$ comprises the step of identifying the elements of the finite-element field $GF(b^{a_1 a_2 \cdots a_h})$ that have respectively multiplicity being equal to, or being a function of, $b^{a_1}, b^{a_1 a_2}, ..., b^{a_1 a_2 \cdots a_h}$.

5.   The construction method according to claim 1, in which said step of establishing biunique correspondences between the elements of the finite-element fields $GF(b^{a_1})$, $GF(b^{a_1 a_2})$, ..., $GF(b^{a_1 a_2 \cdots a_{h-1}})$ and the elements of the finite-element field $GF(b^{a_1 a_2 \cdots a_h})$ isomorphic to them comprises the steps of:

constructing binary polynomial representations of the finite-element fields $GF(b^{a_1})$, $GF(b^{a_1 a_2})$, ..., $GF(b^{a_1 a_2 \cdots a_h})$; and

establishing biunique correspondences between the elements of the finite-element fields $GF(b^{a_1})$, $GF(b^{a_1 a_2})$, ..., $GF(b^{a_1 a_2 \cdots a_{h-1}})$ and the elements of the finite-element field $GF(b^{a_1 a_2 \cdots a_h})$ isomorphic to them, using said binary polynomial representations.

6.   The construction method according to claim 5, in which said binary polynomial representations of the finite-element fields $GF(b^{a_1})$, $GF(b^{a_1 a_2})$, ..., $GF(b^{a_1 a_2 \cdots a_h})$ are constructed using respective primitive polynomials of a degree respectively equal to a_1, $a_1 a_2$, ..., $a_1 a_2 \ldots a_h$ on the finite-element field $GF(2)$, said binary polynomial representations associating, to each element of the respective finite-element fields $GF(b^{a_1})$, $GF(b^{a_1 a_2})$, ..., $GF(b^{a_1 a_2 \cdots a_h})$, a corresponding binary polynomial of degree respectively less than a_1, $a_1 a_2$, ..., $a_1 a_2 \ldots a_h$.

7.   The construction method according to claim 6, in which said step of establishing biunique correspondences between the elements of the finite-element field $GF(b^{a_1 a_2 \cdots a_h})$ and the elements of the finite-element fields $GF(b^{a_1})$, $GF(b^{a_1 a_2})$, ..., $GF(b^{a_1 a_2 \cdots a_{h-1}})$ isomorphic to them comprises the steps of:

for each element of the finite-element field $GF(b^{a_1 a_2 \cdots a_h})$ isomorphic with a corresponding element of one of the finite-element fields $GF(b^{a_1})$, $GF(b^{a_1 a_2})$, ..., $GF(b^{a_1 a_2 \cdots a_{h-1}})$, forming a first binary word with the coefficients of the terms of the binary polynomial associated to said element of $GF(b^{a_1 a_2 \cdots a_h})$, and a second binary word with the coefficients of the terms of the binary polynomial associated to said corresponding element of one of the finite-element fields $GF(b^{a_1})$, $GF(b^{a_1 a_2})$, ..., $GF(b^{a_1 a_2 \cdots a_{h-1}})$;

converting said first binary word into the base $b^{a_1 a_2 \cdots a_h}$, thus obtaining a first symbol, and said second binary word into the base of the finite-element field to which said corresponding element belongs, thus obtaining a second symbol; said first symbol and said second symbol defining the biunique correspondence between said element of the finite-element field $GF(b^{a_1 a_2 \cdots a_h})$ and the corresponding element of one of the finite-element fields $GF(b^{a_1})$, $GF(b^{a_1 a_2})$, ..., $GF(b^{a_1 a_2 \cdots a_{h-1}})$ isomorphic to it.

8.   The construction method according to claim 1, comprising in addition the steps of:

determining, for each element of the multipurpose generating matrix, the number of logic gates necessary for carrying out the operation of multiplication associated to said element; and

abbreviating said multipurpose generating matrix to the value of k initially specified, thus minimizing the number of elements of the finite-element field $GF(b^{a_1 a_2 \cdots a_k})$ that require the largest number of logic gates.

9.   The construction method according to claim 8, in which said step of determining the number of logic gates is performed using said binary polynomial representation of the finite-element field $GF(b^{a_1 a_2 \cdots a_k})$.

10.   A multipurpose error-control method for multilevel memory cells operating with a variable number of storage levels, in particular for memory cells having storage levels that can assume values of the set $\{b^{a_1}, b^{a_1 a_2}, ..., b^{a_1 a_2 \cdots a_k}\}$, said method comprising the steps of:

using an error-control code according to claim 1, said error-control code encoding information words, formed by k q-ary symbols belonging to an alphabet containing q different symbols, with $q \in \{b^{a_1}, b^{a_1 a_2}, ..., b^{a_1 a_2 \cdots a_k}\}$, in corresponding code words formed by n q-ary symbols, with $q = b^{a_1 a_2 \cdots a_k}$, and having an error-correction capacity t, each code word being generated through an operation of multiplication between the corresponding information word and a generating matrix;

converting, symbol by symbol, said information words from the base in which they are represented, which is equal to the number of storage levels at which said memory cells operate, into a base equal to the maximum number of storage levels of said memory cells, using said biunique correspondences;

encoding said converted words, using said error-control code, to obtain respective code words;

storing said code words in a memory;

decoding words read in said memory, using said error-control code; and

converting, symbol by symbol, said decoded words from a base equal to the maximum number of storage levels of said memory cells into a base equal to the number of storage levels at which said memory cells operate, using said biunique correspondences.

11. An error control method for multilevel memory cells operating with a variable number of storage levels, the method comprising:

receiving a first information word having k input symbols each in a first base;

converting the first information word into a second base by converting the input symbols into input symbols in the second base;

encoding the converted first information word into a first codeword having $k + n$ coded symbols in the second base;

writing the first codeword into the multilevel memory cells.

12. The error control method of claim 11, further comprising:

receiving a second information word having k input symbols each in the second base;

encoding the second information word into a second codeword having $k + n$ coded symbols in the second base;

writing the second codeword into the multilevel memory cells.

13. The error control method of claim 11, further comprising:

reading from the multilevel memory cells the first codeword;

decoding the first codeword into an estimated word having k estimated symbols in the second base; and

converting the estimated word into the first base by converting the estimated symbols into estimated symbols in the first base.

14. An error control method for multilevel memory cells operating with a variable number of storage levels, the method comprising:

reading from the multilevel memory cells a codeword having $k + n$ coded symbols in a first base;

decoding the codeword into an estimated word having k estimated symbols in the first base; and

converting the estimated word into a second base by converting the estimated symbols into estimated symbols in the second base.

15. A computer storage device, comprising:

a memory matrix that includes multilevel memory cells capable of storing data in a first base or a second base;

an input transcoder having a word input that receives an information word having k input symbols each in the first base, a control input that receives a control signal indicating whether the memory matrix is operating according to the first base or the second base, and an output that outputs a converted information word in the second base;

an encoder coupled to the output of the input transcoder and structured to encode the converted information word into a codeword having k + n coded symbols in the second base;

a write circuit having an input coupled to the encoder and an output coupled to the memory matrix, the write circuit being structured to writ the codeword into the memory matrix.